Dose Measurement based on Threshold Shift in MOSFET arrays in Commercial SRAMS

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ABSTRACT

A new method using an array of MOS transistors is described for measuring dose absorbed from ionizing radiation. Using the array of MOSFETs in a SRAM, a direct measurement of the number of MOS cells which change as a function of applied bias on the SRAM. Since the input and output of a SRAM used as a dosimeter is completely digital, the measurement of dose is easily accessible by a remote processing system.

INTRODUCTION

Electron-hole pairs are generated in all areas of the circuit when ionizing radiation interacts with microelectronic circuits [1]. Some of these electrons and holes are bound in the various oxides of the structures that make of the integrated circuit. One of the most susceptible single unit electronic items is the MOSFET, or more specifically the oxide between the gate and the channel is very sensitive to radiation effects. In fact, the RADFET dosimeter is based on a MOSFET specifically designed to increase threshold change of the transistor as a function of radiation. The RADFET has several liabilities in measuring dose directly, but the most prevalent is that the support electronics needed to maintain the correct currents and voltage to measure to threshold change are prohibitive to remote measurement needs.

The memory cell of a CMOS SRAM contains 6 MOSFETS. Typically, two p-channel and four n-channel devices make up the SRAM cell. Each of these should respond to radiation like regular MOSFETs. This means that the threshold at which the SRAM cannot be read or cannot hold is logic state should depend on the dose applied. Each cell should have this response on the micro-volume scale so, the cells on the device will yield independent micro-dose measurements for each heavy ion strike. A successful implementation of a SRAM based dosimeter will allow for effortless dosimetry for board level systems.

SRAMs have been studied extensively for TID and SEE response [2-8]. From these studies, it is possible to glean the following facts: SRAM have differing sensitivities to radiation when different biases are applied during irradiation [2-4,8]. SRAMs cells, under certain circumstances, can retain effects of dose on individual cells [4,6,7]. The thin oxide used in CMOS fabrication will not make a dominant contribution to MOSFET threshold response [1,5,8]. These facts easily lend to the premise of SRAM based dosimetry.

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THEORY AND EXPERIMENT

The SRAM cell is used as a static memory device by using two CMOS inverter to lock the value into one another. A simple SRAM cell in shown in Figure 1. One changes the value of the cell by turning the access transistor on, near the bit line, and pulsing in a new value. Reading is essentially the same except sense amps read out the state of the outputs of the inverters.

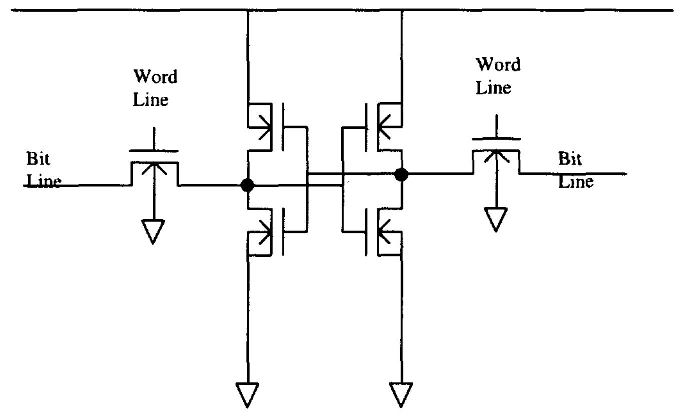

Fig. 1 A CMOS SRAM cell. The threshold shift in the transistors should be sensitive enough to dose to cause readout changes at different operating biases.

The SRAM transistor based dose measurement is possible due to the properties of the 6 MOSFETs that make up the SRAM bit. A CMOS inverter consists of a p-channel and an n-channel MOSFET with the gates tied together (input) and the drains tied together (output). The source of the p-type is connecting to Vcc while the source of the n-type is grounded. The access transistors allow the device to be read or written when activated. The n-channel will have a threshold shift in the positive direction, due to positive charge in the bulk, and then rebound toward the negative direction due to interface traps. The p-channel device has both bulk and interface charge in the positive direction, so its shift will always be in one direction. RADFETs are p-channel devices.

Now unlike discrete MOSFETs, the MOSFETs that make up a SRAM cell may not have a think oxide so the positive bulk trapping. The interface threshold shifts should be the main radiation effect. This will tend to keep the actually SRAM inverter fairly robust in terms of holding the memory state after irradiation. The access transistors should demonstrate the largest radiation induced threshold shift.

The technique to use a SRAM as s dosimeter is to program the device as one would normally. The bias on the SRAM is ramped down and read at reduced bias on the Vcc and all input pins. At some voltage, the number of cells that cannot maintain the programmed state should change. A hypothetical curve that plots the number of cell failures as a function of bias is shown in Figure 2.

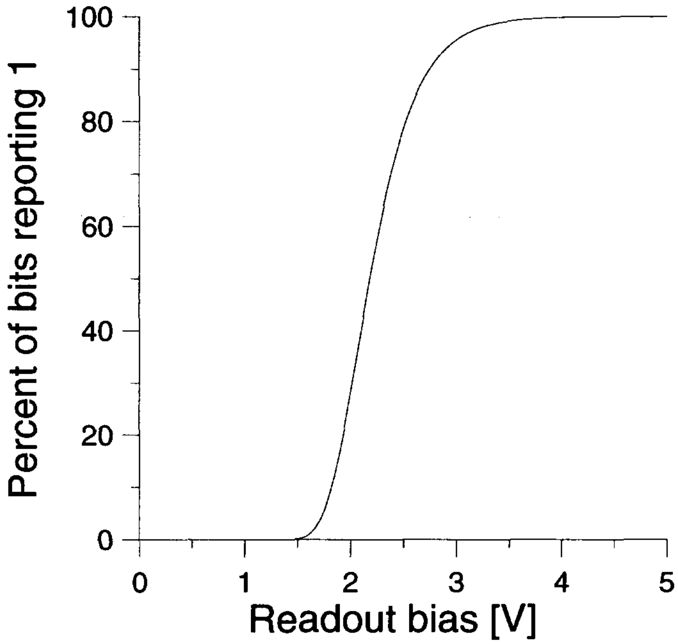

Fig. 2 The fraction of memory states to flip (0 to 1) as a function of the bias at which the device is readout. The device will be programmed at normal operating bias and then readout at a reduce operating bias.

PROCEDURE AND SETUP

The devices used in this study were WMS128k8 SRAMs in a 128kx8 bit format. The test equipment was comprised of two PCs, a power supply, and a specially designed test board. One PC controlled a HP6629A power supply. This allowed precision voltage control and latch-up detection and protection since the PC had millisecond control over the operation of the power supply. Latch-ups were recorded in a separate file during the test.

A dedicated PC controlled the test circuit board designed specifically for this SRAM test to read and write to the DUTs. This setup allows complete freedom to interact with the DUT. The address of a failure and the value at that address were recorded in a file for each run. This allowed for any structure in the SEEs or predilection for certain pattern failure or type of SEU to be observed. A depiction of the setup used is shown in Figure 2.

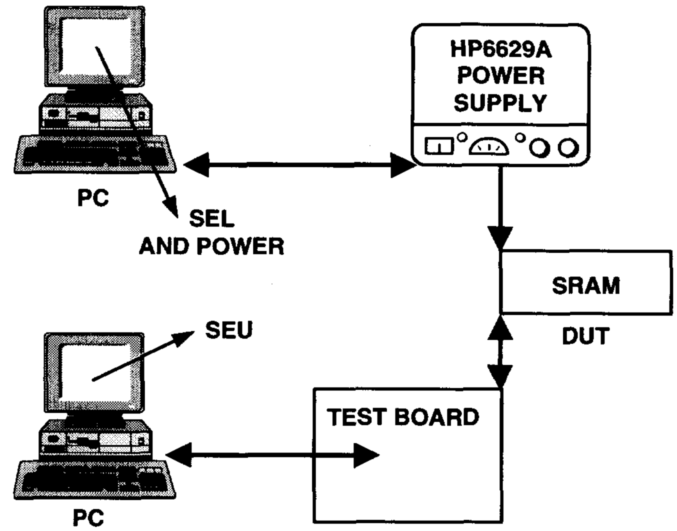

Figure 3. A block diagram of the test system.

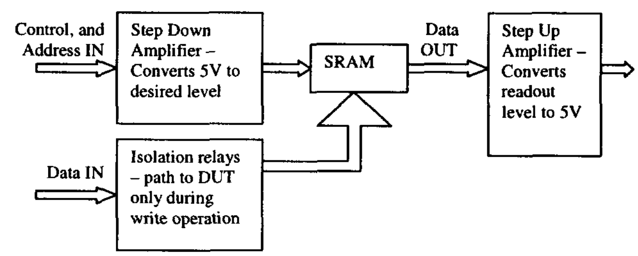

Figure 4. A conceptual diagram of the test board that allows variable biasing of the device.

For this test, the radiation runs are done when the DUT was in stand by mode. The PC cycled through the address space of the DUT, stored address, which exhibited an error, along with the error value, and rewrote the correct pattern to the address.

The Vcc voltage was always set to 5 volts for writing and the operating temperature was approximately 25 °C throughout the study.

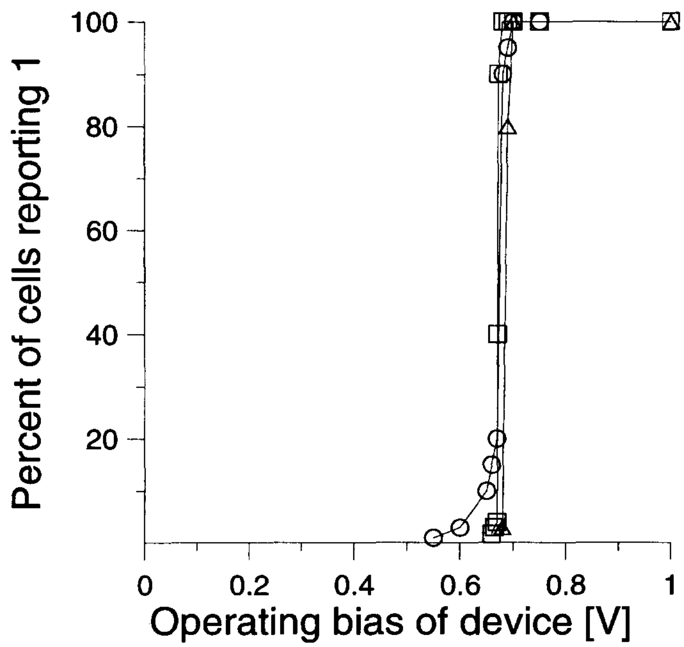

Fig. 5. The percent of memory states to flip (0 to 1) as a function of the readout bias.

The cumulative distribution of the percent of cells that could be readout is shown in Fig. 5. The distribution appears to be rather narrow. This distribution would be rather insensitive to the small shifts induced by low level exposures. Variations in processing and differences in circuit layout among circuit elements presumably do not contribute.

A calibration run of the device was done at the JPL Cobalt-60 source. A device was exposed to 10krad then readout. This was repeated two more times. The issue of the hardness of the SRAM sense amplifier kept the total dose under 30krad. The supply current was monitored during the experiment to ensure that the current stayed within specifications. After the biased device is irradiated with all the pins floating, he device is programmed at an operation bias of 5V and then the voltage is ramped down and read. The metric is then number of cells that could not report the programmed state.

RESULTS

The result of a device being irradiated to 30krad in 10krad steps is shown in Figure 6. The shift is toward higher voltages at which the device can no longer hold it state. If the device is readout below this bias, and then readout above the threshold bias, the correct pattern is recovered. This shows that for this protocol, the access transistor is experiencing the threshold shift. If the pins are not allowed to float during irradiation, this behavior may change. The application here would be to load a pattern into a SRAM designated for TID measurement and sweep through voltages when a measurement is desired. The change in operating bias that yields the 50% duty cycle would correlate to dose.

A calibration curve for this protocol is shown in Figure 7. The change is small when compared to digital levels but easily programmable with digital to analog converter. A process could easily control voltage and measure the number of cells not reporting as programmed.

A more elucidating analysis is shown in Figure 8. The change in biasing at which 50% of the cells fail to report the state to which each was programmed is plotted versus TID level on a log-log scale. It is clear that change in bias is the metric and depends on applied dose in a power law relationship.

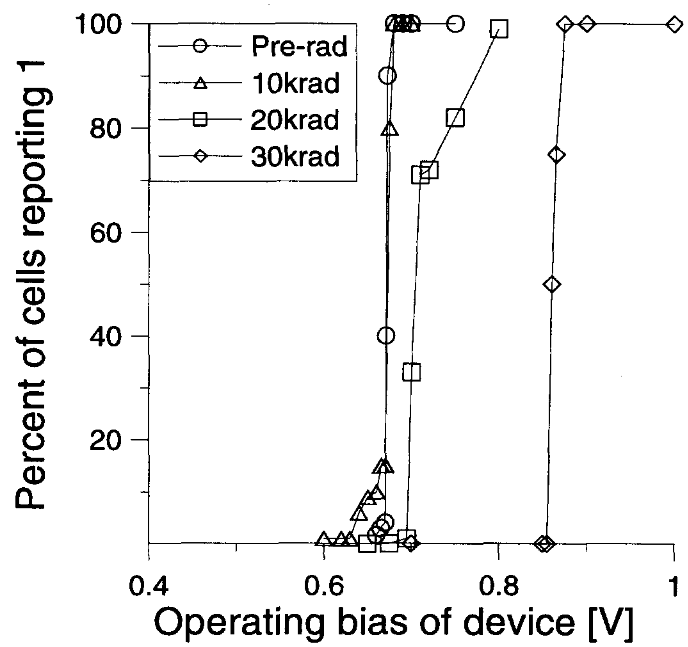

Fig. 6 The percent of memory states to flip (0 to 1) as a function of the readout bias for four different TID levels.

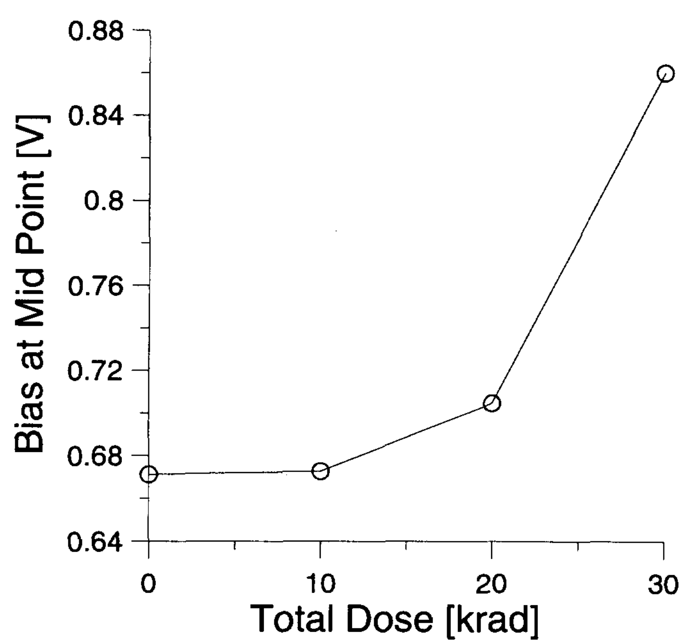

Fig. 7. The readout bias at which 50 percent of the cells could not report the 1 that each was programmed. The ordinate values are found by calculating at what bias there is 50% response from the traces in Figure 6.

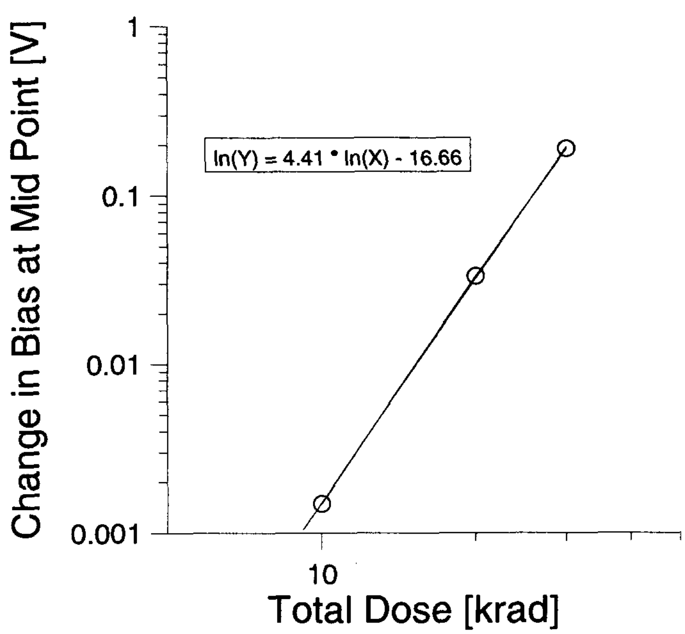

Fig. 8. The change in readout bias at which 50 percent of the cells could not report the 1 that each was programmed. The ordinate values are found from Figure 7 by subtracting the bias value at each level by the bias level at 0 krad.

CONCLUSIONS

A new microdosimetry approach using SRAMs has been developed. Ionizing radiation changes the lowest operating bias at which the device can be readout.

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